

Recombination Rate Coefficients and Line Emissivity

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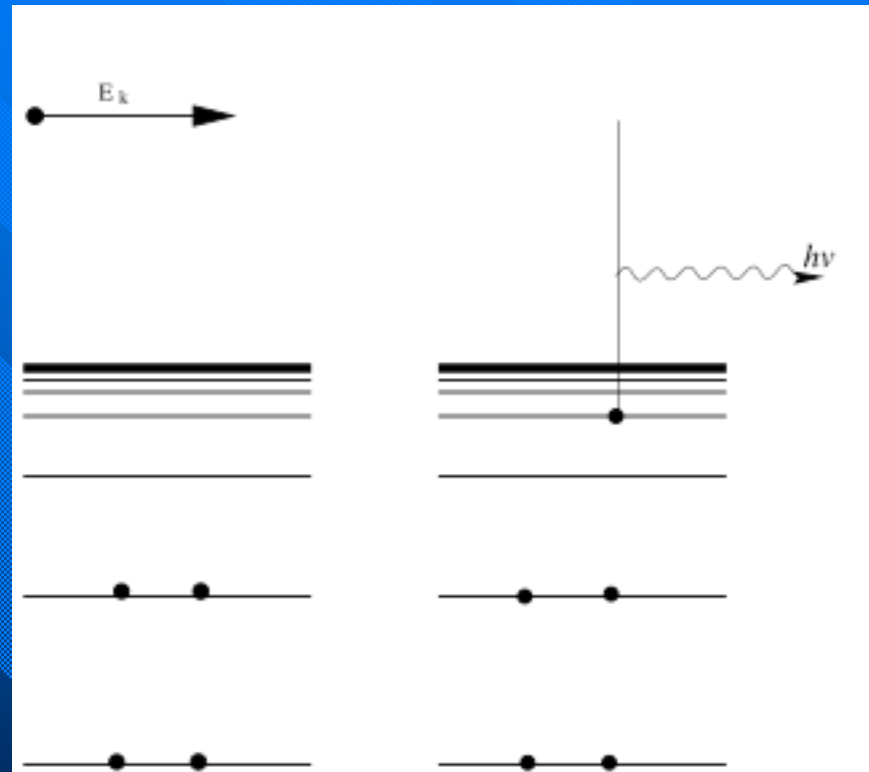
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Overview

- ✓ Radiative Recombination.
- ✓ Two Types of Dielectronic Recombination
 $\Delta N = 0$ and $\Delta N > 0$.
- ✓ Recombination Rate Coefficients and Ionization Equilibrium.
- ✓ Recombination Emission in Photoionized plasmas

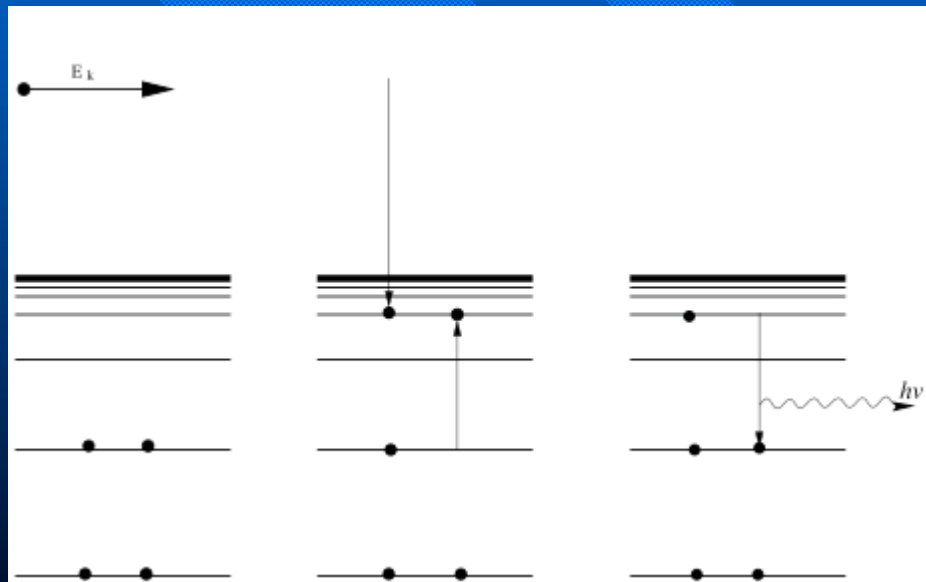
Radiative Recombination

- ✓ RR is the direct capture of a free electron to a bound state.
- ✓ RR continuum.
- ✓ Radiative cascades following RR.



Dielectronic Recombination

- ✓ DR can be treated as a two step process.
Dielectronic Capture + Radiative Stabilization.
- ✓ DR satellite emission.
- ✓ Radiative cascades following DR.



Classification of DR

- ✓ Three bound orbitals are involved.
- ✓ $nl\ n'l'\ n''l''$
- ✓ $n' = n$, Low temperature DR.
- ✓ $n' > n$, High temperature DR.
- ✓ K-shell ions:
 $1s\ 2l\ nl',\ 1s\ 3l\ nl',\ \dots$
- ✓ L-shell ions:
 $2l\ 2l'\ nl'',\ 2l\ 3l'\ nl'',\ 2l\ 4l'\ nl'',\ \dots$

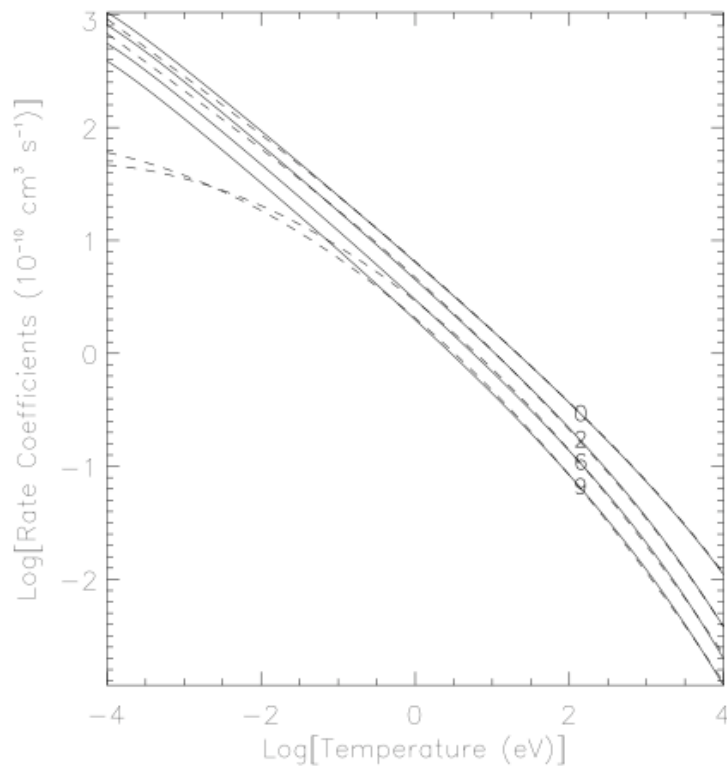
Atomic Code

- ✓ I have recently written a relativistic atomic code, which is ideally suited for calculation of atomic data needed in X-ray spectroscopy.
- ✓ The Flexible Atomic Code (FAC), much like HULLAC, is based on distorted-wave approximation for electron-ion collision dynamics, and is publicly available. Currently at:
<ftp://space.mit.edu/pub/mfgu/fac/>
- ✓ The RR and DR results reported here are exclusively calculated with FAC.

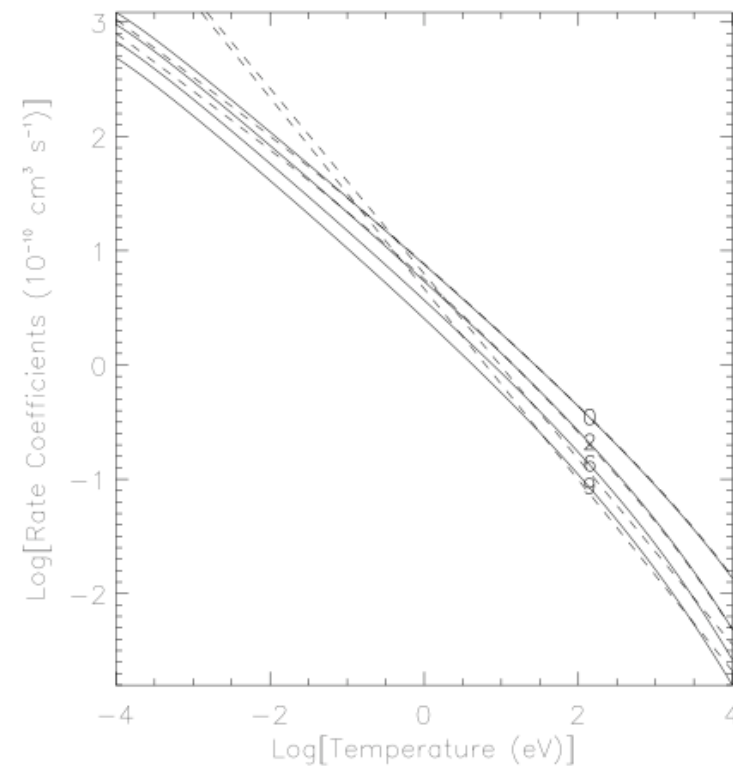
RR Rate Coefficients

- ✓ RR is a relatively simple process. Existing data for Bare, H-like, He-like, and Ne-like ions are accurate (Verner & Ferland, 1996, ApJS, 103, 467)
- ✓ For other isoelectronic sequences of Iron ions, data from Arnaud & Raymond (1992, ApJ, 139, 776) are relatively accurate.
- ✓ I have calculated Distorted-Wave RR rate coefficients for K-shell and L-shell ions of Mg, Si, S, Ar, Ca, Fe, and Ni.

Comparison of RR Rates



Fe Ions

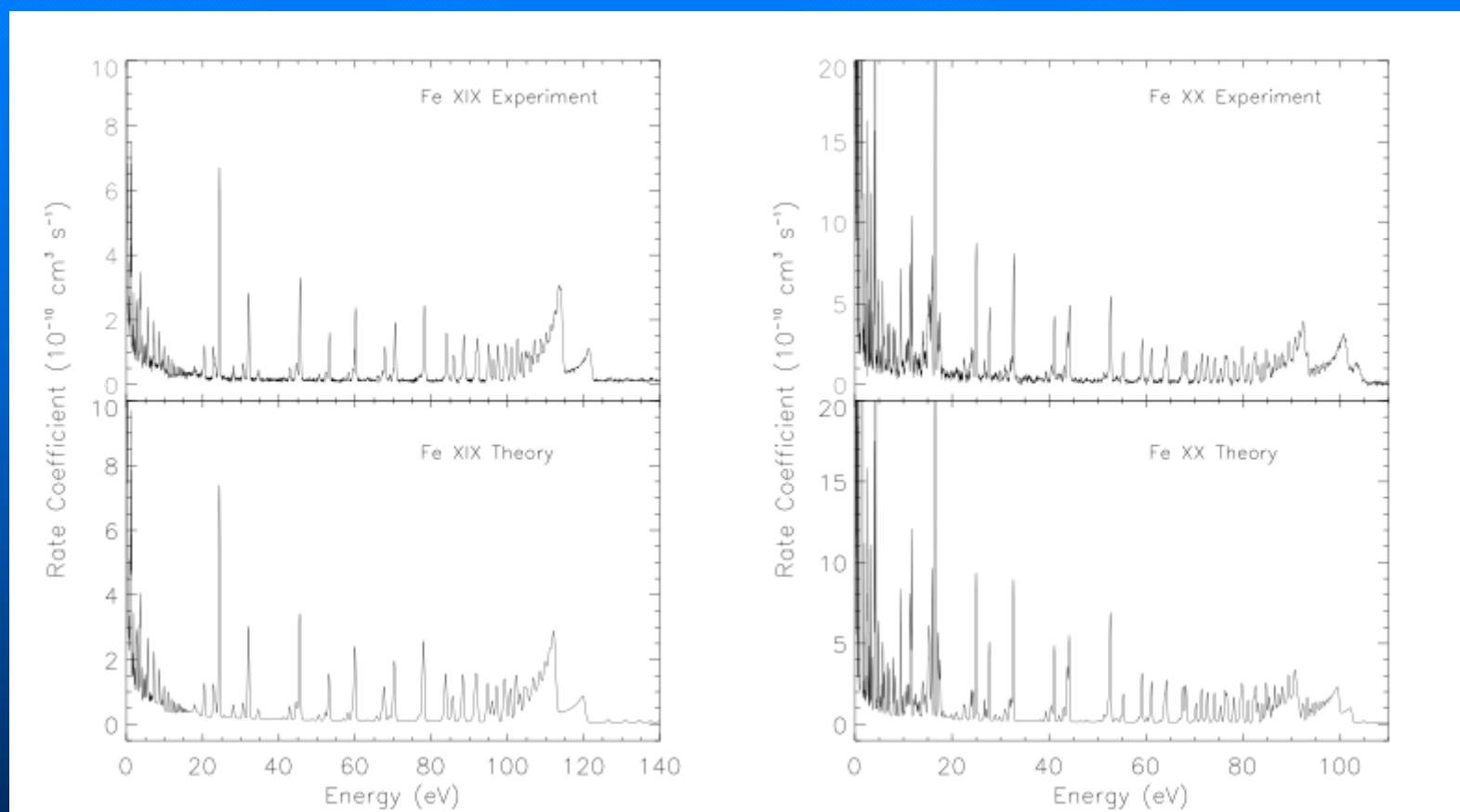


Ni Ions

$\Delta N = 0$ DR For L-shell Ions

- ✓ Detailed calculation were made for Mg, Si, S, Ar, Ca, Fe and Ni.
- ✓ Special adjustment of resonance energies using the NIST database.
- ✓ Comparison can be made with the storage ring measurements of Savin et al. (ApJS, 123, 687 & ApJS 138, 337) for several Fe ions.

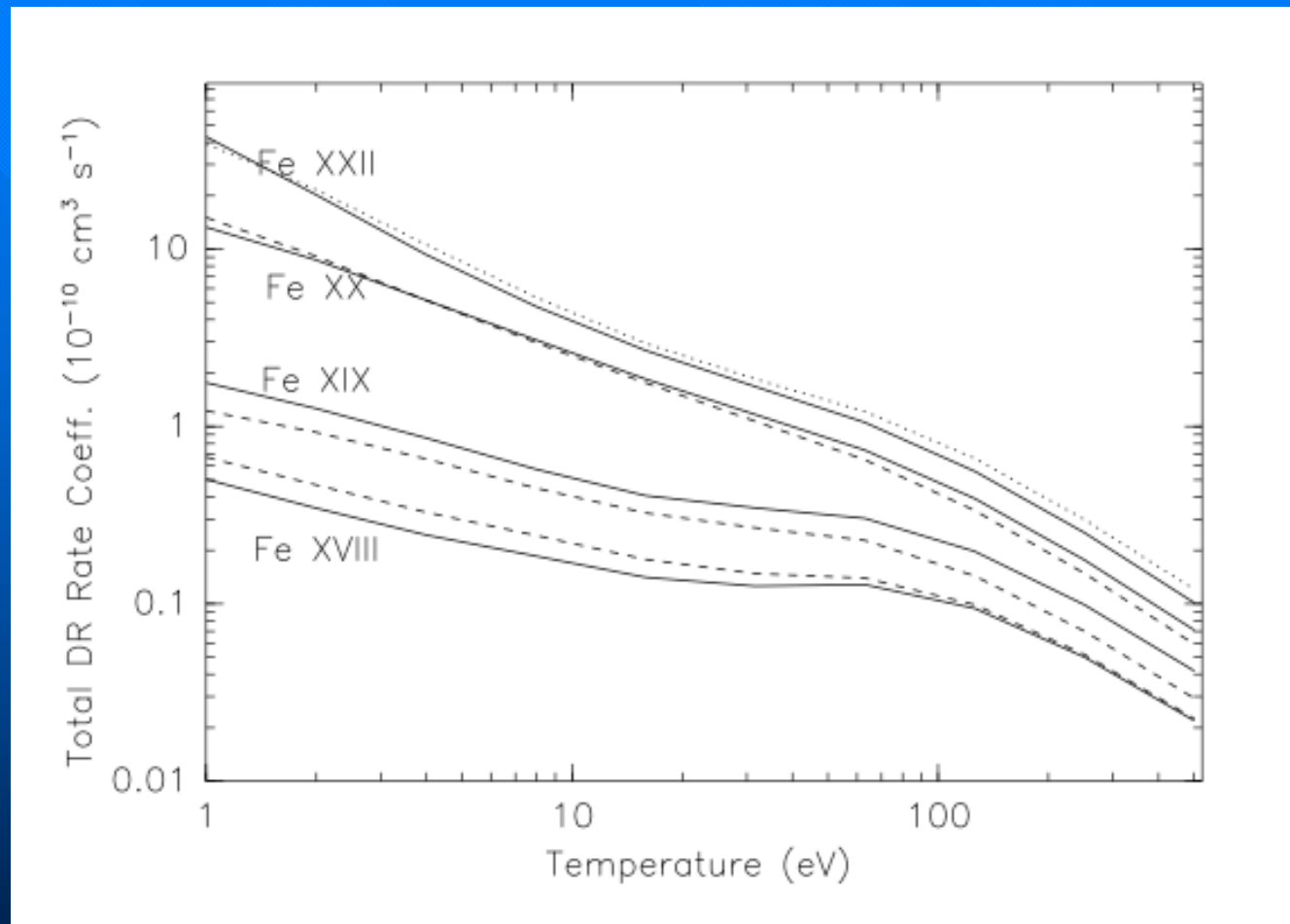
$\Delta N = 0$ DR of Fe XIX and XX



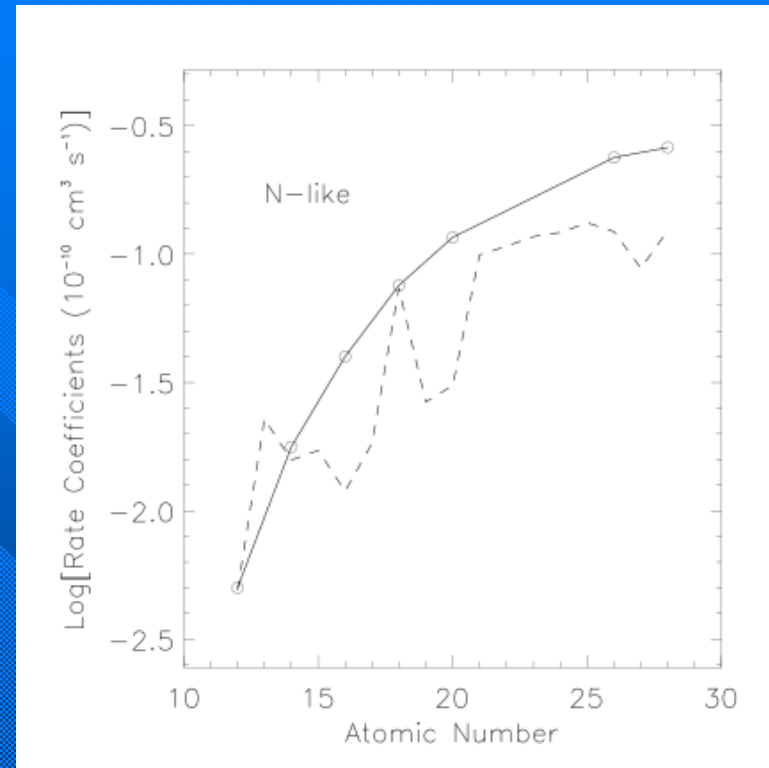
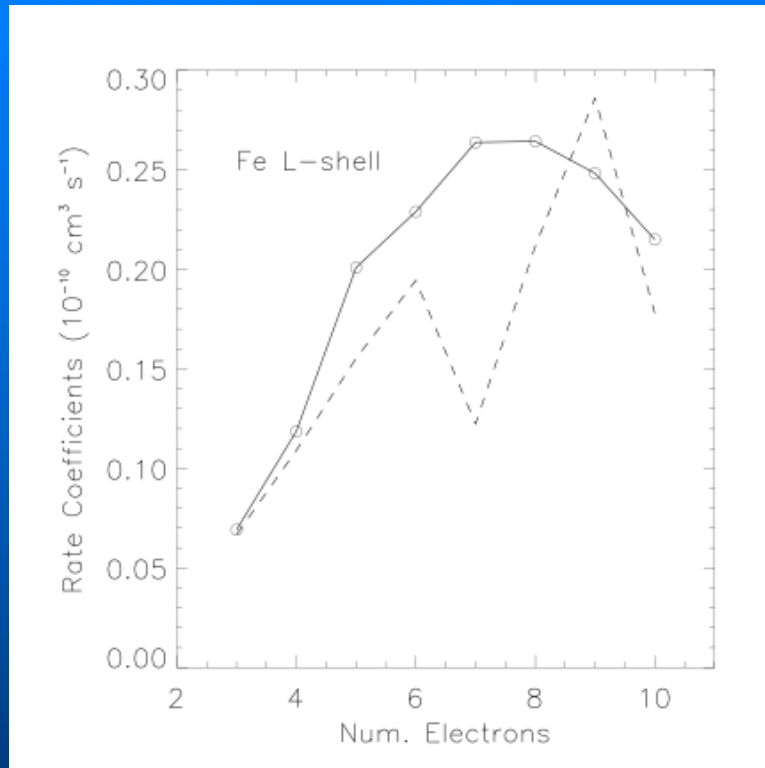
Fe XIX

Fe XX

$\Delta N = 0$ DR Rate Coefficients



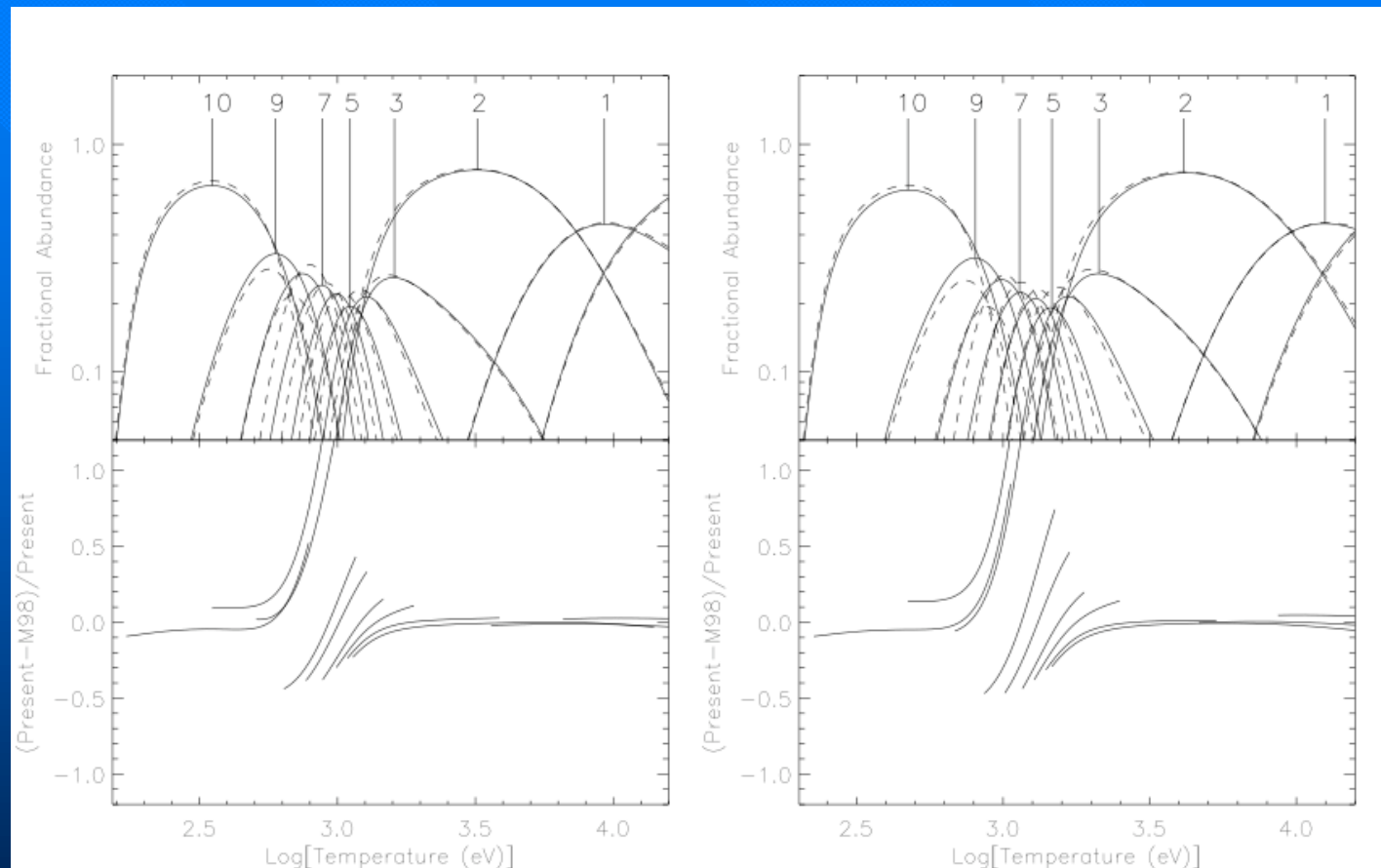
$\Delta N > 0$ DR Rate Coefficients



Solid line: Present results at $T = 1 \text{ keV}$

Dashed line: Mazzota et al. A&AS, 133, 403

Coronal Ionization Equilibrium



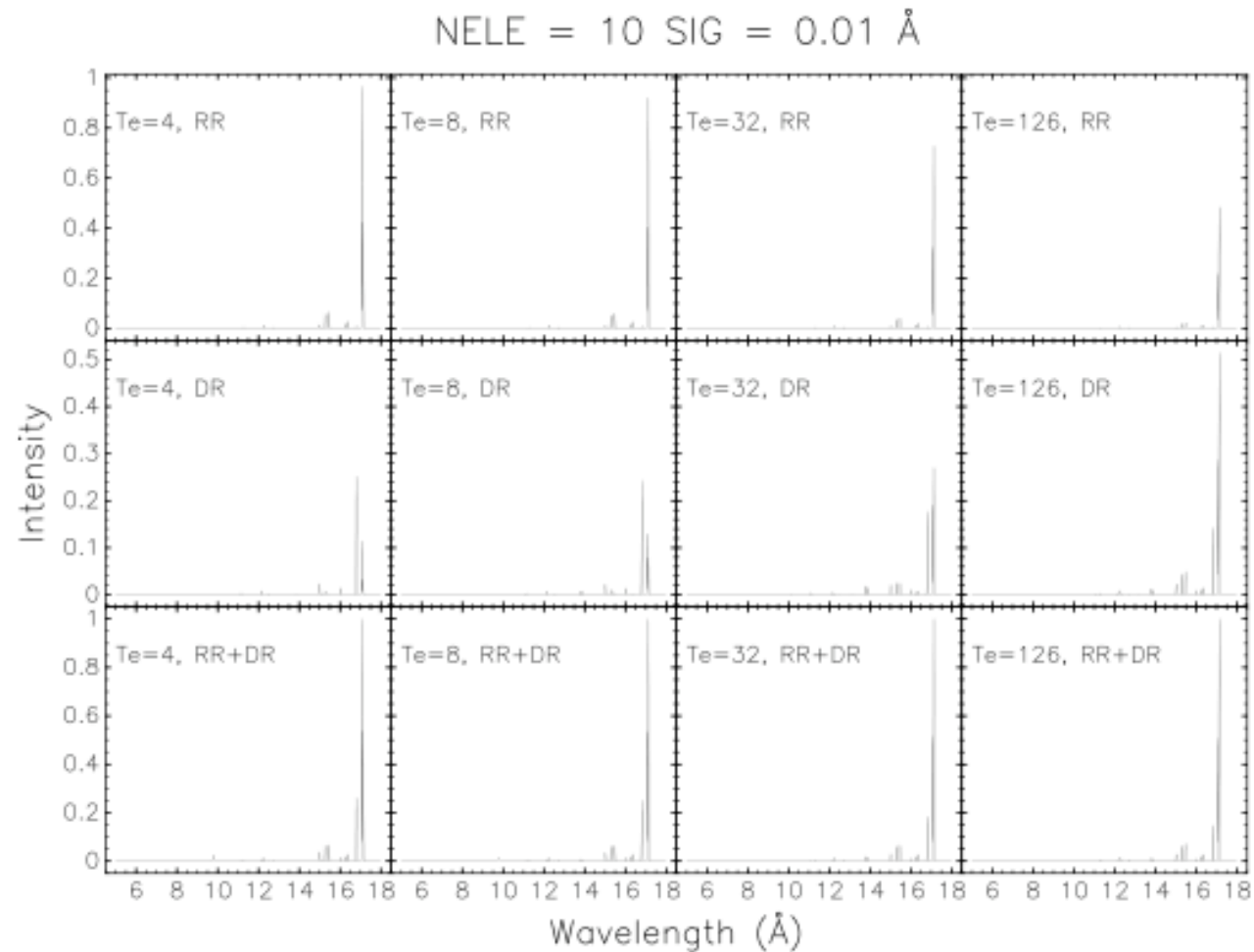
Fe

Ni

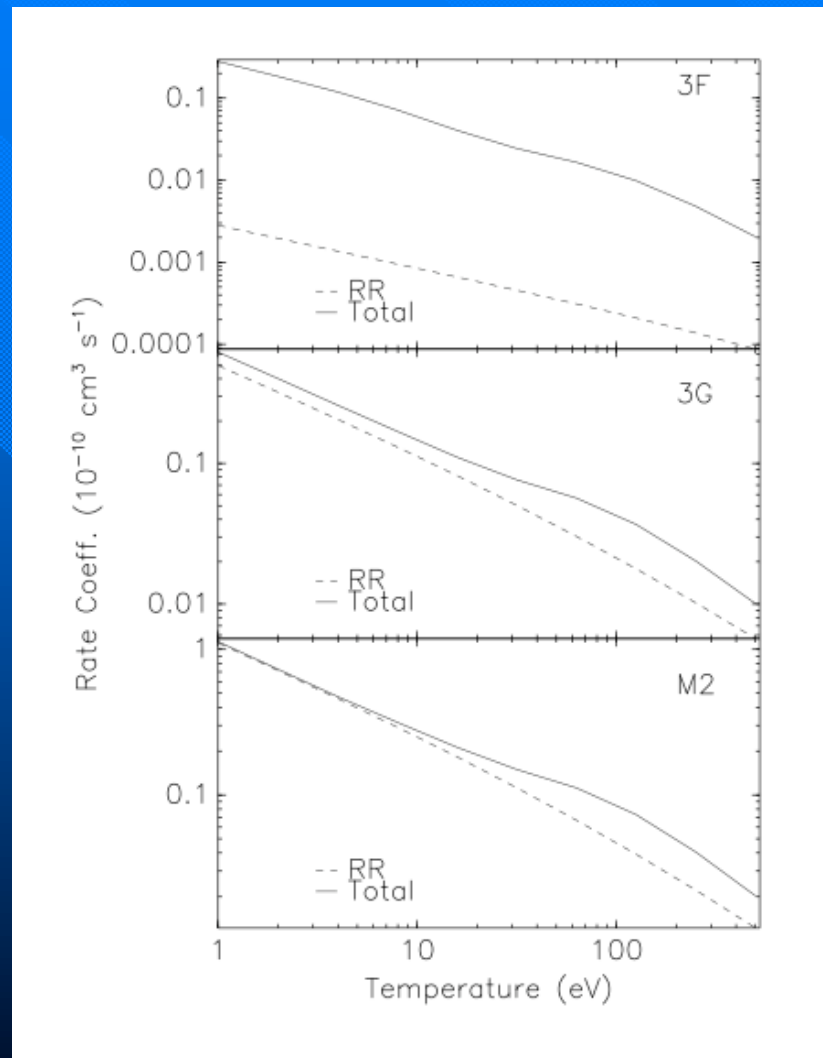
Recombination Emission

- ✓ Important for photoionized plasmas. XRB, AGN, ...
- ✓ Line spectra qualitatively different from that of collision driven plasmas. He-like triplet ratio, Fe L-shell 3s/3d ratio.
- ✓ Emission following RR has been extensively studied.
- ✓ Emission following low temperature DR of L-shell ions is important, more data needed.

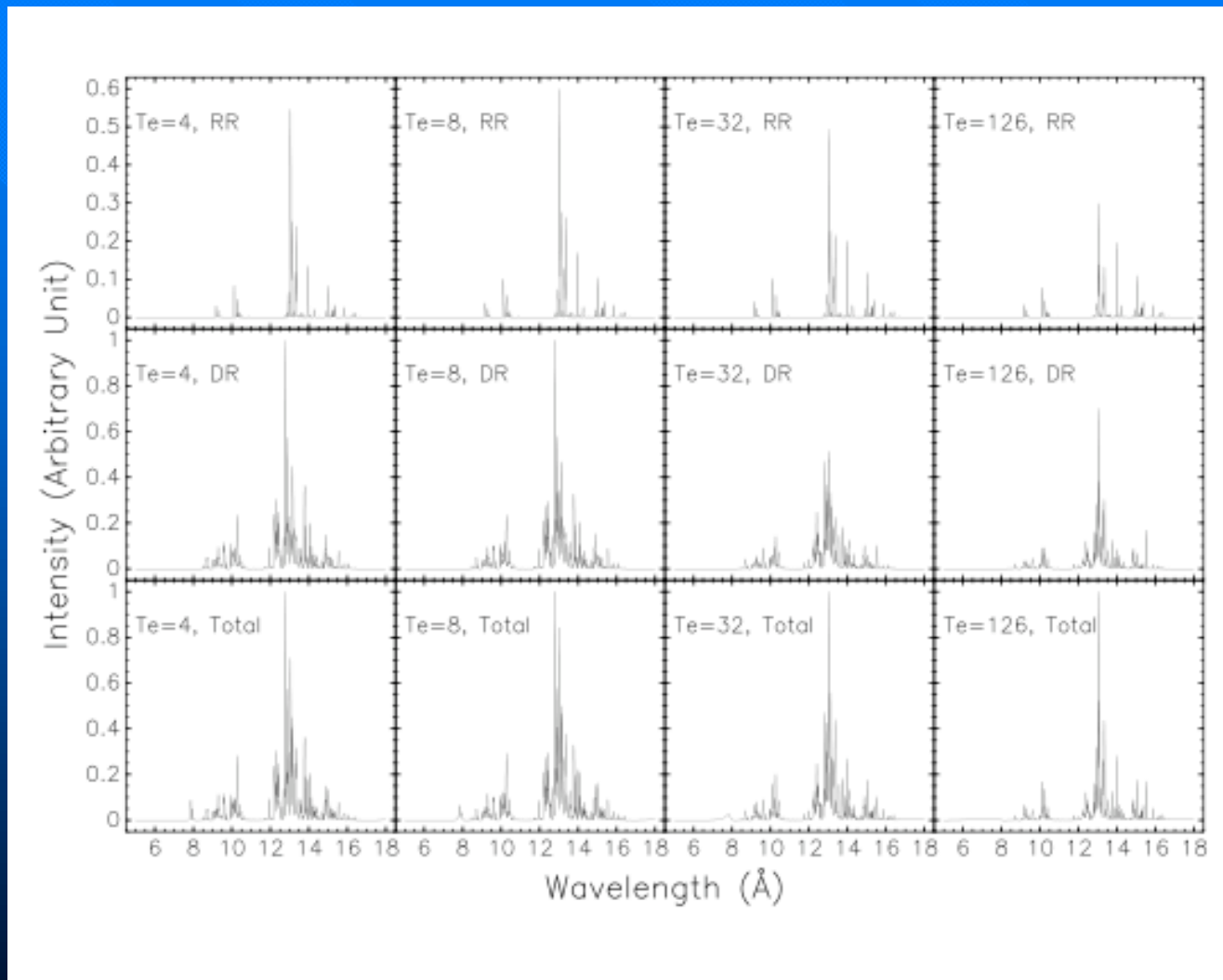
Fe XVII Spectrum



Line emissivities of 3F, 3G, M2



Fe XX Spectrum



Summary

- ✓ Systematic calculations of recombination rate coefficients of K-shell and L-shell ions.
- ✓ There are problems in the currently used RR and DR rates.
- ✓ Low temperature DR is important for the line formation of L-shell ions in photoionized plasmas.